Final Summary Report

THEORETICAL AND EXPERIMENTAL ANALYSIS OF THE ELECTROMAGNETIC SCATTERING AND RADIATIVE PROPERTIES OF TERRAIN, WITH EMPHASIS ON LUNAR-LIKE SURFACES

The Ohio State University

ElectroScience Laboratory

(formerly Antenna Laboratory)

Department of Electrical Engineering

Columbus, Ohio 43212

FINAL REPORT 1388-27

7 November 1967

Grant Number NsG-213-61

National Aeronautics and Space Administration

Office of Grants and Research Contracts

Washington, D.C. 20546

NOTICES

REPORT 1388-27

REPORT
by
The Ohio State University ElectroScience Laboratory
(Formerly Antenna Laboratory)
Columbus, Ohio 43212

Sponsor	National Aeronautics and Space Administration Office of Grants and Research Contracts Washington, D.C. 20546
Grant Number	NsG-213-61
Investigation of	Theoretical and Experimental Analysis of the Electromagnetic Scattering and Radiative Properties of Terrain, with Emphasis on Lunar-Like Surfaces
Subject of Report	Final Summary Report
Submitted by	ElectroScience Laboratory The Ohio State University Department of Electrical Engineering
Date	7 November 1967

ABSTRACT

This report summarizes the work conducted under this grant during the past year. Included are summaries of the results of the CW lunar Doppler experiment and the lunar two-frequency experiment.

TABLE OF CONTENTS

FINAL SUMMARY REPORT

I. INTRODUCTION

The investigations under this grant have been directed toward (1) determining what information can be obtained about the physical characteristics of remote surfaces (e.g., planetary and lunar surfaces) by radar methods, and (2) obtaining experimental results which serve both to verify theoretical results of (1) above and to provide information about the lunar surface. Work under (1) completed during the preceding year and given in reports number 1388-17, 18 and 19 (References 15, 16, 17) was extended to include bistatic scattering from statistically rough surfaces. The results of the experimental studies, completed during the past year, are given in reports 1388-22, 24 (References 20 and 22) and are summarized in this report. A review of rough surface analysis is given in report 1388-26 (Reference 24).

II. THEORETICAL STUDIES

During the preceding year under this grant a significant contribution to the theory of scattering from statistically rough surfaces was presented in reports number 1388-17, 18 and 19 (References 15, 16 and 17). The theory at that time was restricted to the case of backscatter. During the past year the theory was improved and extended to include bistatic scattering. The results of these efforts are found in report 1388-25 (Reference 23).

III. EXPERIMENTAL STUDIES

A. Doppler Spectrum Experiment

Analysis of the data which were acquired during the preceding year was completed. The results are reported in Reference 20. In summary it was concluded that the lunar RMS surface slope at a wavelength of 13.2 cm is about 15°; the lunar cross section is approximately 6 per cent for direct (linear) polarization and about 0.4 per cent for cross polarization (both $\pm$ 3 dB); and the average dielectric constant of the moon's surface is $\epsilon \approx 2.6$.

By means of the comparison (Fig. 1) of the experimental backscattering parameter with values derived theoretically in Reference 16,

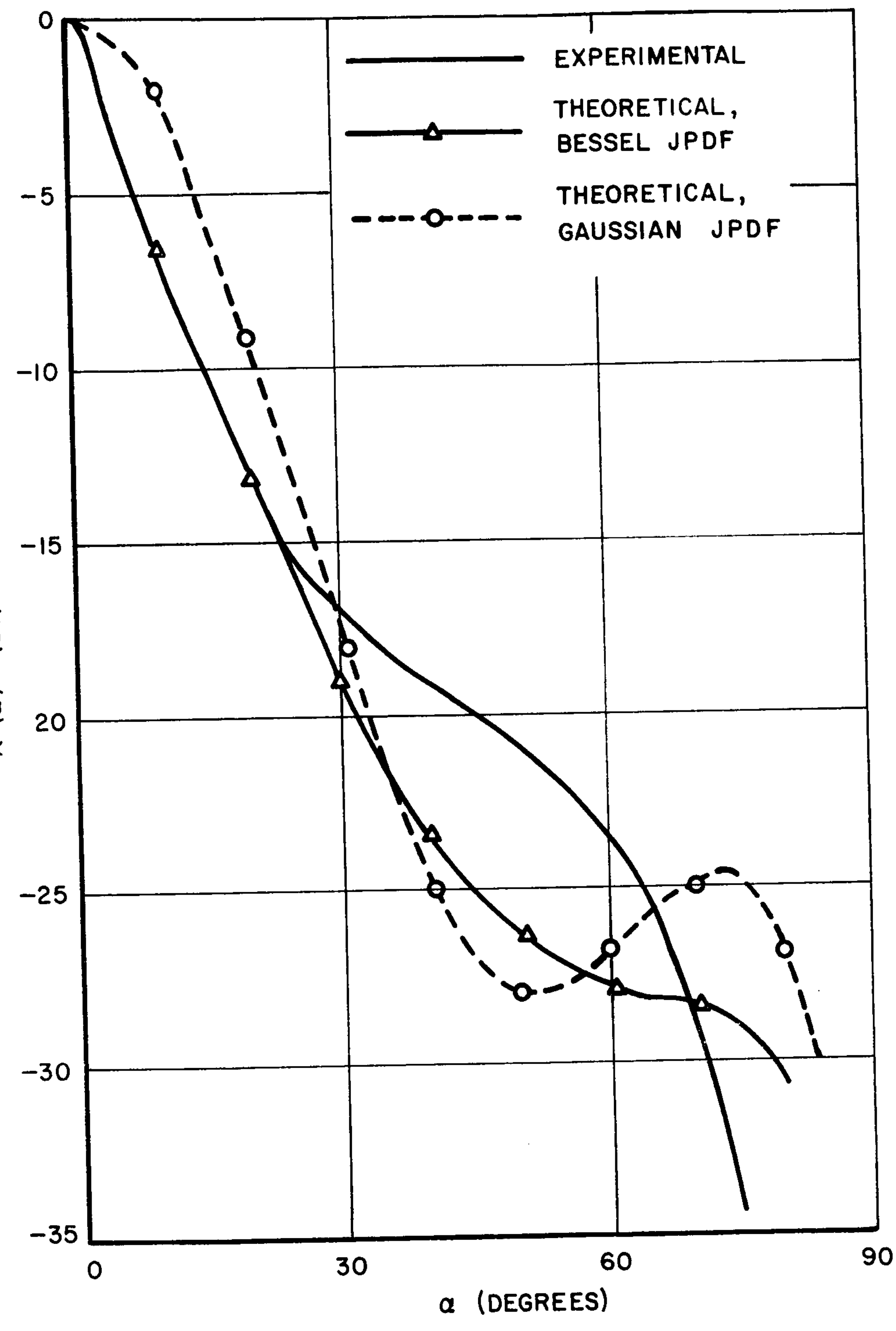

Fig. 1. Comparison of experimental backscattering parameter, $\gamma(\alpha)$, with theoretical predictions.

it was concluded that the modified Bessel joint probability density function is a more accurate model for the description of the lunar surface than is the more familiar Gaussian joint probability density function.

B. Two-Frequency Experiment

Reference 17 describes a "two-frequency experiment" which is designed to obtain estimates of the RMS height of a remote rough surface. Unlike the effective RMS surface slope, which has been shown both experimentally (Fig. 2) and theoretically (Reference 16) to be a function of wavelength, the RMS surface height is essentially independent of the examining wavelength, depending primarily on the RMS height of the largest scale structure.

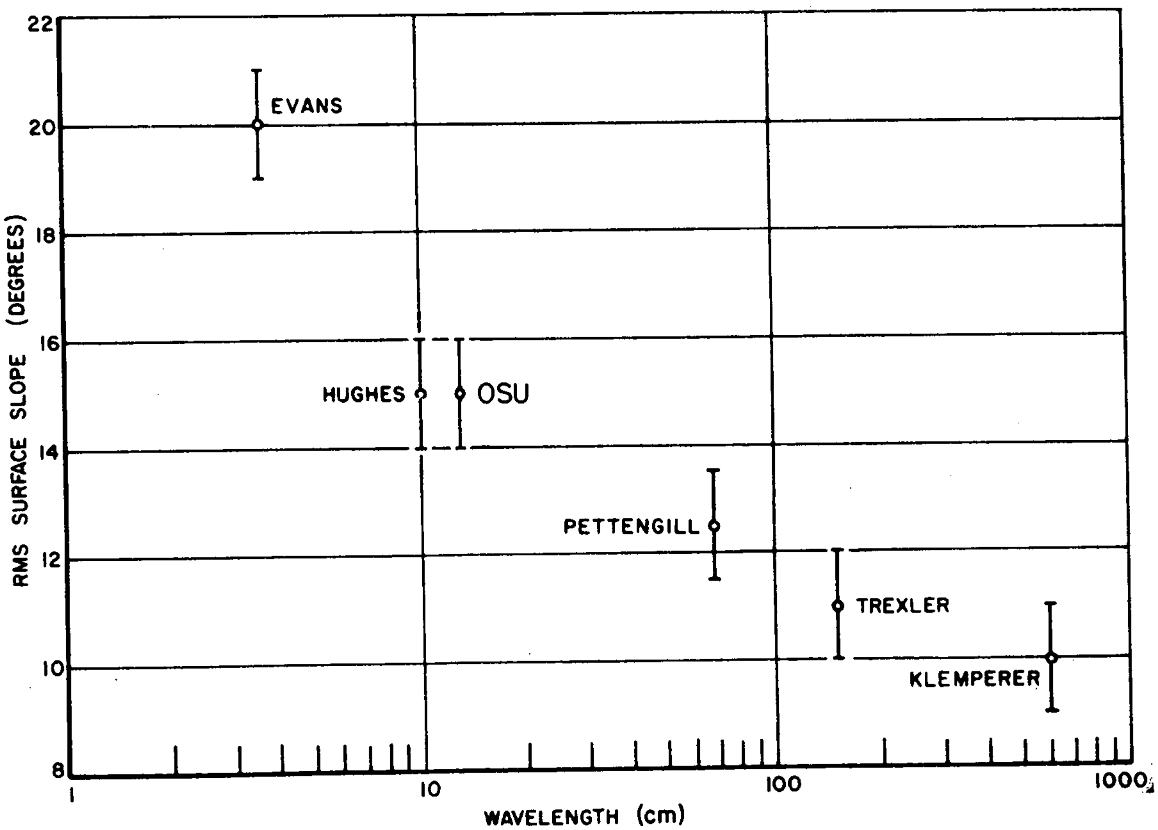

Fig. 2. Effective RMS surface slope as a function of wavelength.

Data were acquired during the preceding year in an attempt to verify the theory of the "two-frequency" experiment. Although the experimental configuration did not correspond exactly to that prescribed in Reference 17 and only a small amount of data was taken, it is felt that the results that were obtained do tend to confirm the essential correctness of the ideas behind the two-frequency experiment. The "enhanced" correlation function $P_{exp}(\Delta k\sigma) = \sqrt{R\Delta k}\ \rho_{xy}(\Delta f)$ where $\rho_{xy}(\Delta f)$ is the correlation coefficient of the two signals, R is the radius of the moon and $\Delta k = 2\pi\Delta f/c$, with Δf the frequency separation of the signals and c the velocity of light, is plotted in Fig. 3. After normalizing $P_{exp}(\Delta k\sigma)$ with respect to an estimated "initial value" of 0.84, the experimental results can be compared (Fig. 4) with the theoretically[19] predicted behavior. It is seen that the normalized, enhanced correlation function reaches half its initial value at a frequency separation of about 60 kHz which corresponds, according to the relation[19] $2\sigma^2\ \Delta k^2 = 0.693$, to an RMS surface height, σ, of about 500 meters.

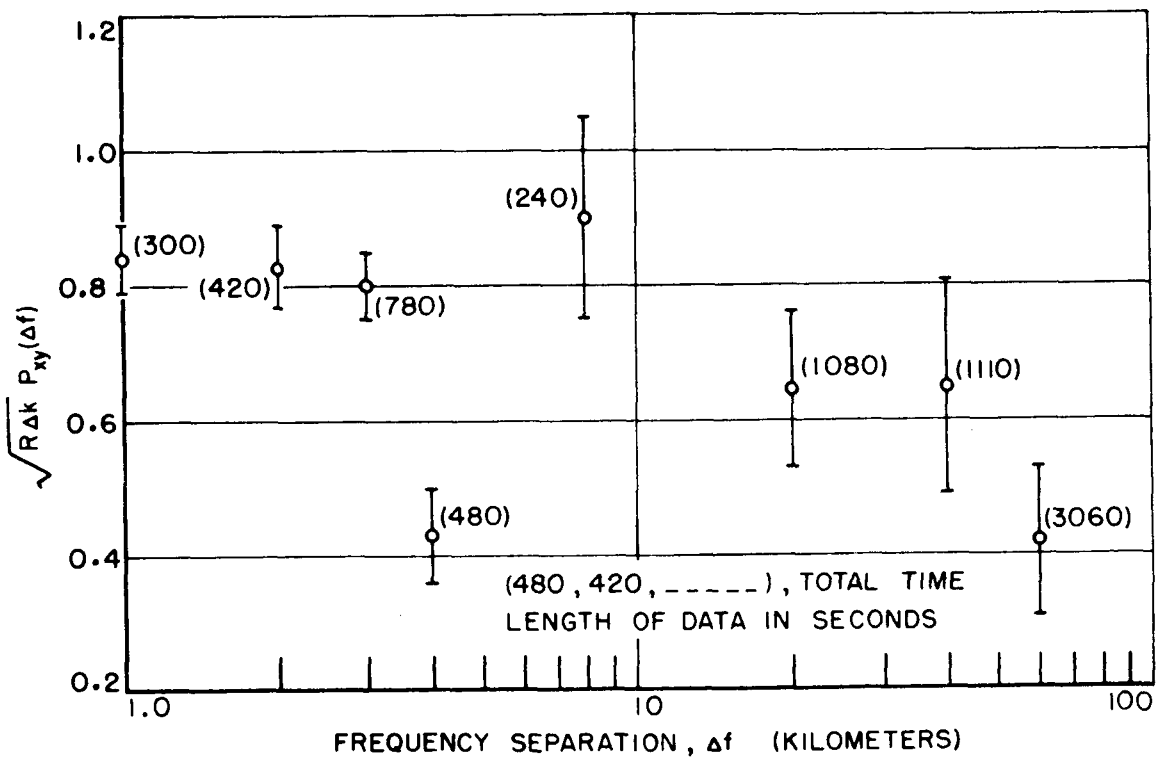

Fig. 3. Correlation of backscattered fields at two frequencies.

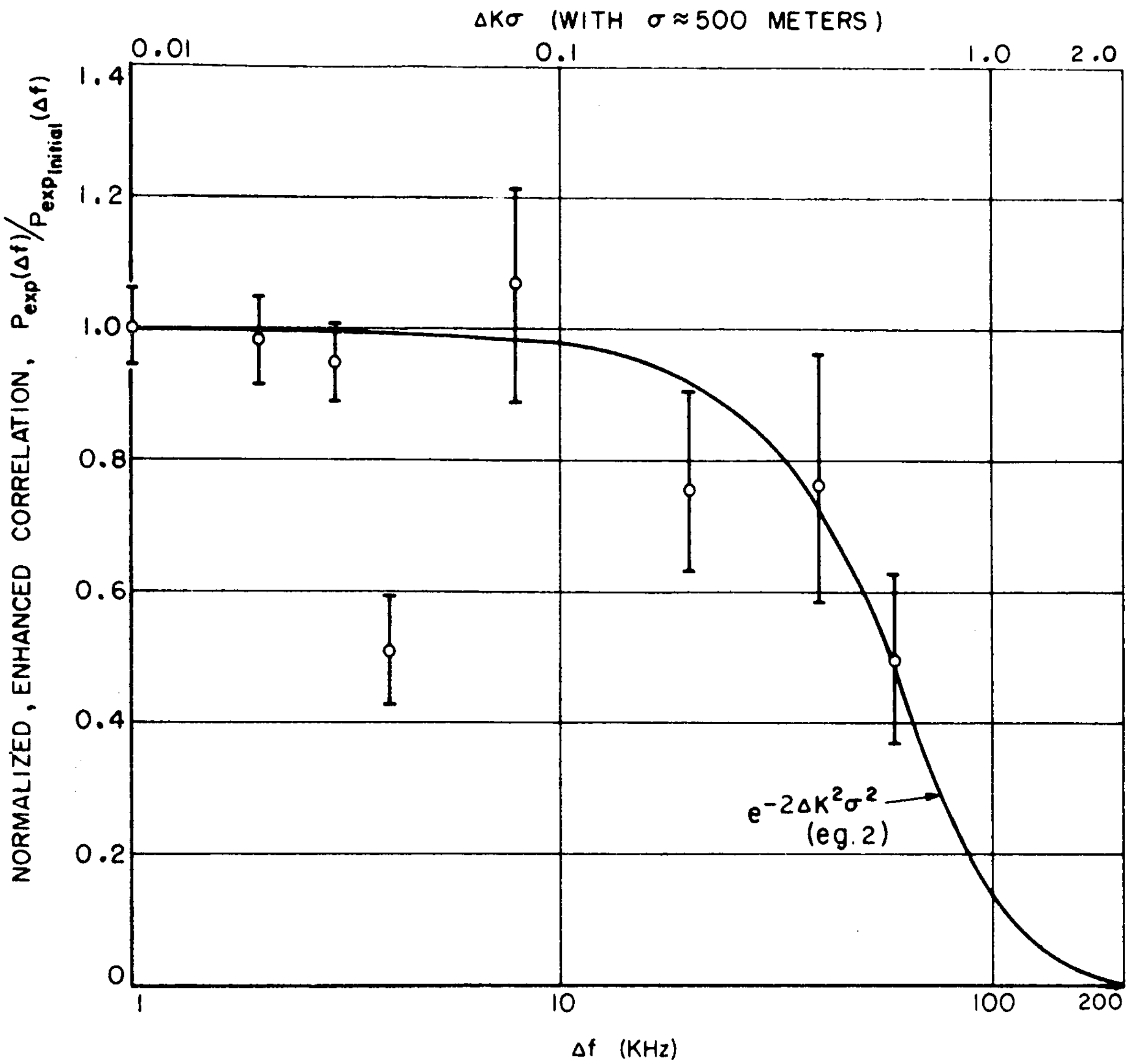

Fig. 4. Normalized, enhanced correlation function compared with theoretical predictions.

IV. SUGGESTIONS FOR FUTURE WORK

The preceding sections of this report describe a number of advances in the understanding of the problem of studying planetary surfaces by radar methods. There are, however, two areas in which further work could profitably be undertaken.

The first is undoubtedly a repetition of the two frequency experiment, with equipment suitable for predetection correlation measurements over a larger range of frequency separation (out to, say, $\Delta f = 120$ KC). It would be desirable to use a carrier frequency no higher than a few GHz, since it is not known by how much the noise due to the diffuse component of the lunar scattering may reduce the observable correlation between the two frequency components.

The second area where further studies, both theoretical, are needed, is in the interpretation of the scattering properties of remote surfaces. Such studies would include not only further theoretical development of the two frequency method (i.e., to include post detection correlation experiments, non-physical optics surface models, etc.), but also studies of the single frequency experiment.

For example, present interpretation of the lunar surface is based on an arbitrary division of the observed cross-section into two components, a further separation of each component into a directivity and a reflectivity factor, with the reflectivity given by a simple normal incidence Fresnel coefficient. Such a procedure is known to give inconsistent results for terrestrial surfaces, yet is the basis for the "accepted" value of the lunar dielectric constant. It is clear that a study of the diffuse component, in particular, (i.e., return from surfaces with multiple scattering or scattering from edges and cusps) is needed to relate the observed scattering to the geometrical and dielectric properties of the surface. Of particular interest here, for example, would be the use of the depolarized component as a diagnostic of surface roughness, or the interpretation of compound surfaces, where the question of interest is the relation between the fraction of a total surface covered by a given process, and the overall scattering patterns. In short, the apparent success of the single-scattering physical optics approximation should not be allowed to obscure the fact that many surfaces cannot be handled that way, and that much study of other scattering mechanisms must be carried out before the problems of remote sensing by radar are solved.

REFERENCES

The following reports were prepared under Grant NsG-213-61, National Aeronautics and Space Administration, Office of Grants and Research Contracts, Washington, D.C. 20546

1. Ott, R.H., "A Theoretical Model for Scattering from Rough Surfaces, with Application to the Moon and Sea," Report 1388-1, 10 November 1961.

2. Peake, W.H., "The Apparent Temperature of Isolated Objects," Report 1388-2, 1 October 1961. (AD 295 193)

3. Mathis, H.F., "Reflection of Circularly Polarized Radar Wave from a Very Rough Surface," Report 1388-3, 15 May 1962.

4. Semi-Annual Engineering Report, Report 1388-5, 1 July 1962.

5. Annual Summary Report, Report 1388-7, 1 November 1962.

6. Compton, R.T., Jr., "The Solution of an Integral Equation for the Lunar Scattering Function," Report 1388-8, 1 April 1963.

7. Peake, W.H. and Taylor, R.C., "Radar Back-Scattering Measurements from 'Moon-Like' Surfaces," Report 1388-9, 1 May 1963.

8. Semi-Annual Report, Report 1388-10, 1 June 1963.

9. Eberle, J.W., "The Use of an Oscilloscope for the Measurement of SNR," Report 1388-11, 15 January 1964.

10. Semi-Annual Report, Report 1388-12, 1 November 1963.

11. Barrick, D.E., "Normalization of Bistatic Radar Return," Report 1388-13, 15 January 1964.

12. Semi-Annual Report, Report 1388-14, 1 May 1964.

13. Zolnay, S.L., "Look Angles for a Celestial Body," Report 1388-15, 6 October 1964.

14. Barrick, D.E., "Summary of Concepts and Transformations Commonly Used in the Matrix Description of Polarized Waves," Report 1388-16, 9 April 1965.

15. Barrick, D.E., "Two Experiments Yielding Lunar Surface Information Employing Polarized Radar Waves," Report 1388-17, 15 August 1965.

16. Barrick, D.E., "A More Exact Theory of Backscattering from Statistically Rough Surfaces," Report 1388-18, 31 August 1965.

17. Barrick, D.E., "Determination of RMS Height of a Rough Surface Using Radar Waves," Report 1388-19, 31 August 1965.

18. Barrick, D.E., "Theoretical Curves of Backscattering Cross Sections of Rough Surfaces for Several Polarization States Using Two Statisitical Models," Report 1388-20, 31 August 1965.

19. Suzuki, Tsutomu, "The Principle and Design of a Vernier FM Radar System," Report 1388-21, 31 May 1966.

20. Peake, W.H., Turpin, R.H., and Taylor, R.C., "OSU Lunar Doppler Experiment," Report 1388-22, 1 August 1967.

21. Turpin, R.H., "Notes on Digital Spectral Analysis," Report 1388-23, 6 February 1967.

22. Peake, W.H., Turpin, R.H., and Taylor, R.C., "OSU Lunar Two-Frequency Experiment," Report 1388-24, 27 July 1967.

23. Du, Li-jen, "A More Exact Theory of Bistatic Scattering from Statistically Rough Surfaces," Report 1388-25.

24. Peake, W.H., and Barrick, D.E., "Scattering from Surfaces with Different Roughness Scales; Analysis and Interpretation," Report 1388-26.